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Parallels between the Recognition-Primed Decision Model and Case-Based Reasoning

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Abstract

Evidence has been brought about the utility of the Naturalistic Decision-Making (NDM) model in military Command and Control (C^2). NDM may be seen as a good representation of the environment in which C^2 activities take place. NDM represents situations characterized by uncertainty, time pressure, high stakes, ill-structured problems, competing or conflicting goals, etc. Developed from a human factor perspective, the Recognition-Primed Decision model (RPD) represents how humans make decisions in the NDM context. According to the RPD model, the pattern recognition and mental simulation phases seem determinant for the human performance. Therefore, from a technological perspective, Decision Support Systems (DSS) must support these phases to efficiently support the human decision-making processes in the NDM context. In business management and manufacturing contexts, the Case-Based Reasoning (CBR) approach has been successfully used to support decisional processes. This approach, in which pattern recognition and simulation are key components, concentrates on knowledge acquisition, and the cognitive areas of learning. The contexts of CBR applications may be different from that defined by the NDM. However, there are some noticeable similarities between the CBR and the RPD architectures. This document presents these similarities and discusses the possible application of CBR concepts to the decision-making processes involved in the NDM context.

Résumé

On a pu démontrer l'utilité de l'approche « Naturalistic Decision-Making » (NDM) pour représenter l'environnement dans lequel les activités liées au Commandement et Contrôle (C^2) sont conduites. Le NDM représente les situations marquées par l'incertitude, la pression temporelle, des enjeux importants, des prises de décision dynamiques, des problèmes mal définis, des conflits entre les buts et objectifs, etc. Cette approche, développée à partir d'une perspective "facteur humain", propose le modèle de « Recognition-Primed Decision » (RPD) pour expliquer le processus décisionnel de l'humain dans le contexte du C^2. Selon le modèle RPD, la reconnaissance de patrons et la simulation mentale sont des phases déterminantes dans le processus décisionnel de l'être humain. Ainsi, les systèmes d'aide à la décision (SAD), développés à partir d'une perspective technologique, doivent être compatibles avec ces phases afin d'offrir un support efficace à l'humain dans ses activités de prise de décision dans un environnement NDM. Dans le vaste monde des affaires et de l'industrie, les SAD construits à partir de l'approche « Case-Based Reasoning » (CBR) ont connu beaucoup de succès dans le support du processus décisionnel de l'humain. L'approche CBR, pour laquelle la reconnaissance de patrons et la simulation sont des composantes clés, se concentre sur l'acquisition et l'apprentissage de connaissances. Les environnements pour lesquels ont été utilisés de tels systèmes sont différents de ceux représentés par le NDM. Cependant, on constate des similarités intéressantes entre les architectures respectives du CBR et du RPD. Ce document présente ces similarités et une réflexion quant à l'éventuelle utilisation du CBR pour supporter le processus décisionnel dans un environnement NDM.

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Executive Summary

Command and Control (C^2) activities are embedded in a complex environment characterized by the availability of a huge load of information. To cope with this complexity, C^2 requires qualities inherent to humans such as decision-making abilities, inductive reasoning, initiative, creativity and the notions of responsibility, leadership and accountability. These qualities are indispensable when situation involves unexpected events that may be produced by an intelligent source (e.g., the enemy). However, even if these qualities are essential, they are not sufficient to ensure an optimal human performance in C^2 environments. In fact, the characteristics of C^2 environments combined with the advancement in threat technology significantly challenge the C^2 process, and therefore require the support of technology to complement human capabilities and address its limitations.

The decision-making process can be seen as a major component of C^2. A considerable amount of effort has been devoted to develop systems that support this process in C^2. It is crucial to develop Decision Support Systems (DSS) that recognize the contribution of both the technology and the human in the C^2 process, while favouring the interaction between the human and the support system. Indeed, an optimal degree of interaction between the DSS and the human is essential. In that respect, there are noticeable similarities between the Case-Based Reasoning (CBR) approach, developed from a technological perspective, and the Recognition-Primed Decision (RPD) model, developed from a human factor perspective of Naturalistic Decision Making (NDM), a model applicable to C^2.

In both CBR and RPD, pattern recognition and simulation capabilities are key components of the decision-making process. In RPD, the human performance in the decision-making activity is determined by the recognition of patterns in the environment that lead to the selection of a given course of action. In case of uncertainty in the recognition pattern process, the human uses mental simulations to evaluate the most plausible course of action selected from the information observed in the environment. Similarly, CBR systems recognize information in the environment and, from a matching process with their database, select the most plausible course of action.

Pattern recognition and mental simulation processes produce an important workload for human memory and attentional resources. Since human resources are limited, the decision-making performance is highly influenced by this workload. DSS are required to support the human in the execution of these processes. CBR systems seem compatible with the human information processing and as a consequence, may efficiently support the human in the decision-making activities. CBR systems may be very useful to support the human in the pattern recognition and mental simulation processes. By supporting the human during these processes, the CBR systems may reduce the workload and the demand in memory and attentional resources. Because decision-making in C^2 environments is a very challenging task, reducing the workload, or making available memory and attentional resources for other important concurrent tasks, can make all the difference between a positive and a negative outcome.

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Sommaire

Les activités liées au Commandement et Contrôle (C^2) sont effectuées dans un environnement très complexe caractérisé par une quantité importante d'information. Afin de composer avec cette complexité, le C^2 requiert des habiletés propres à l'être humain telles que sa capacité de prise de décision, son intuition, son initiative, sa créativité et des notions de responsabilité et de leadership. Ces qualités sont essentielles lorsque la situation implique des événements imprévus pouvant avoir été causés par une source intelligente (p.ex., ennemi). Bien qu'essentielles, ces qualités sont toutefois insuffisantes pour assurer une performance humaine optimale dans ces environnements. En fait, les caractéristiques déterminant l'environnement de C^2 combinées à l'avancement des menaces technologiques posent un défi considérable au processus de C^2 qui requiert alors le soutien de la technologie pour complémenter les capacités et habiletés de l'être humain.

Beaucoup d'efforts sont déployés afin de développer des systèmes pouvant aider l'humain dans le processus de prise de décision qui est essentiel au C^2. Il est primordial de développer des systèmes qui reconnaissent et permettent les contributions de l'humain et de la technologie dans le processus de C^2, tout en favorisant une interaction efficace entre l'humain et le système. En fait, un niveau optimal d'interaction entre le DSS et l'humain est essentiel. En ce sens, on constate des similarités remarquables entre l'approche Case-Based Reasoning (CBR), développée à partir d'une perspective technologique et le modèle de Recognition-Primed Decision (RPD), développé à partir de l'approche facteur humain du Naturalistic Decision Making (NDM).

Pour le CBR et le RPD, la reconnaissance de patrons et les capacités de simulation jouent un rôle primordial dans le processus décisionnel. Dans le RPD, la performance de l'humain dans les activités de prise de décision est déterminée par la reconnaissance de patrons dans l'environnement qui permet le choix d'une suite d'actions donnée. Lorsqu'il y a incertitude dans la reconnaissance des patrons, l'humain utilise la simulation mentale pour évaluer la suite d'actions la plus plausible qui a été sélectionnée à partir de l'information observée dans l'environnement. De façon similaire, les systèmes CBR reconnaissent l'information dans l'environnement et choisissent, à partir d'un processus d'appariement avec leurs bases de données, la meilleure suite d'actions.

Les processus de reconnaissance de patrons et de simulation mentale imposent une importante charge mentale pour les ressources mnémoniques et attentionnelles. Puisque l'humain possède des ressources mnémoniques et attentionnelles limitées, sa performance dans la tâche de prise de décision sera grandement influencée par l'importance de la charge mentale. Les DSS sont alors nécessaires afin d'aider l'humain dans l'exécution de ces activités. Les systèmes CBR semblent compatibles avec le traitement de l'information de l'être humain et par conséquent, peuvent efficacement supporter l'humain dans son processus décisionnel. Ces systèmes peuvent être très utiles dans les processus de reconnaissance de patrons et de simulations. En supportant l'humain dans ces processus, les systèmes CBR peuvent contribuer à réduire la charge de travail mentale et la demande imposée aux ressources mnémoniques et attentionnelles. Puisque la prise de décision dans l'environnement de C^2 est une tâche très exigeante, la réduction de la charge de travail mentale et la mise en disponibilité des

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ressources mnémoniques et attentionnelles pour d'autres tâches importantes exécutées simultanément peuvent faire toute la différence entre un résultat positif et un résultat négatif.

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1. Introduction

For several years now, researchers involved with either of the command and control (C^2) theory or the C^2 process have been trying to reach consensus over a definition. Although this consensus has not yet been fully attained, common processes may be identified over the various definitions. These processes are: a) *observation*, that consists in gathering information and data from the situation; b) *situation assessment*, that includes data processing concerning the current situation; c) *course of action selection*, that includes decision-making and the choice of a course of action; and d) *implementation of the course of action*. These processes are compatible with those defined in Boyd's OODA loop (Observe-Orient-Decide-Act) presented in Figure 1 and used by numerous scientists (e.g., Paradis, Treurniet, & Roy, 1998) to describe the C^2 process at a very high level.

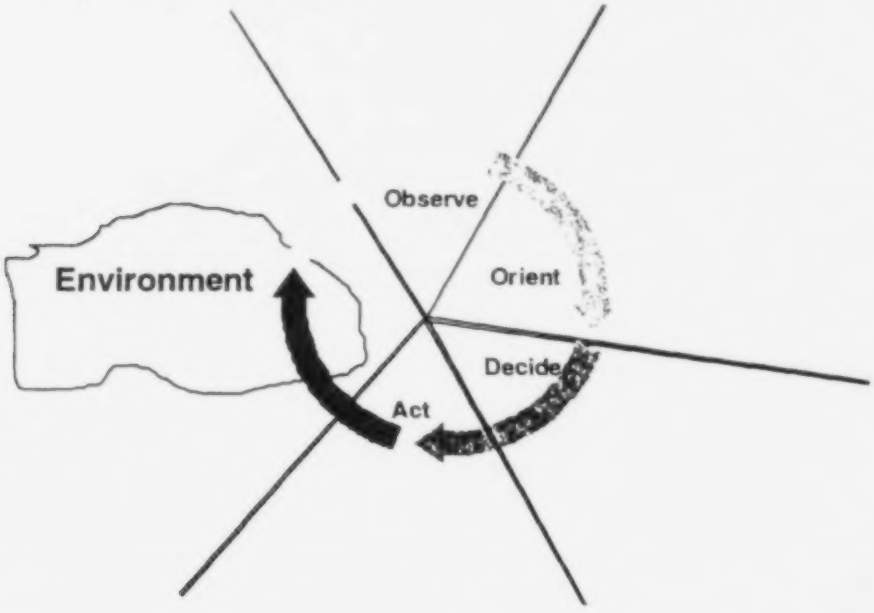

Figure 1. *Boyd's OODA Loop*

The environment in which each process of the OODA loop is performed is very complex. Moreover, unpredictable events occur that may threaten the fulfilment of the decision-maker's mission. Their origins may be hostile and undefined. As shown in Figure 2, the complexity of the environment and the occurrence of unpredictable events raise the need for both the deductive capacities of Decision Support Systems (DSS) and human's inductive reasoning capabilities. For instance, the deductive capabilities of the system are required to cope with the complexity of the environment and for the analyses of multiple hypotheses explaining the source of unpredictable events. Human inductive reasoning capabilities are required to cope

with the changing, uncertain and threatening conditions induced by the occurrence of unpredicted events.

According to Schneiderman (1998), computer-based systems have great deductive capabilities. However, they can hardly make inductive reasoning. On the other hand, humans can hardly deal with several hypotheses at the same time, but have the capacity to make inductive reasoning. To adequately perform each process of the OODA loop, an integration of both human and computer strengths is required. The challenge facing system designers is thus to create a DSS that takes advantage of both human and computer strengths.

To reach this goal, the DSS design team must be composed of engineers, system designers and human factor specialists (as shown in Figure 2). All specialists involved must work in collaboration and understand which tasks or processes of the OODA loop must be performed by the system itself (automation), by the human, or by a combination of the system and the human. The processes supported by the decision aid must be familiar to the decision-maker and appropriate to the situation at hand (Smith & Marshall, 1997). Smith and Marshall raise the importance of a rich interaction between the user and the decision aid. They also suggest that this can only occur if the user is able to relate to the aid and the processes it represents. Therefore, compatibility between the system and the human decision-making processes is required.

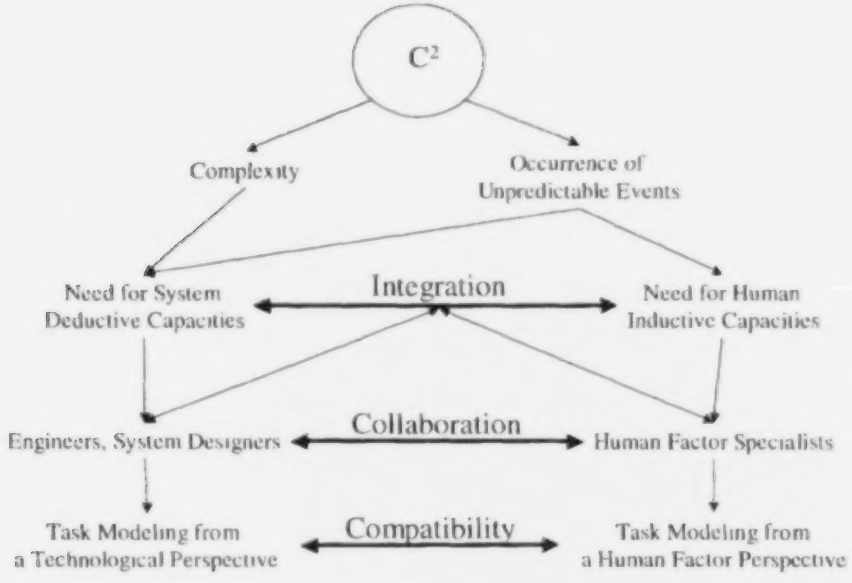

Figure 2. Collaboration between the Specialists Involved in the Design Process of a Computer-Based DSS

The model supporting the DSS design must be compatible with the model representing the human decision-making process. An incompatibility between these models may lead to an

increase in the complexity of the environment, thereby imposing higher processing demands to the human. The main goal of the present document is to discuss the high level of compatibility and the similarities that exist between the Recognition-Primed Decision (RPD) Model and Case-Based Reasoning (CBR) apporach. The RPD model is developed from a human factor perspective and represents the human decision-making process in a C^2 environment. The CBR approach is part of intelligent systems that are developed from a technological perspective to support human in decision-making activities. The document is organized as follows. Section 2 briefly presents the CBR approach. The RPD model is presented in section 3. Parallels are established between the CBR approach and the RPD model in section 4. Conclusions are draw in section 5.

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2. Case-Based Reasoning Model

For the purpose of this document, it is not necessary to present the technical details (i.e. the mechanics of the actual algorithms) of the CBR approach. Then, only the key concepts are briefly discussed.

2.1 Problem-Solving and Decision-Making

CBR has been applied successfully to a variety of domains and tasks. From a technological perspective, CBR is categorized as a problem-solving paradigm. However, from a human factor perspective, the term "problem-solving" must be considered in a wider sense. There exists an overlap in the cognitive processes involved in human problem-solving and decision-making activities. According to Proctor & Van Zandt (1994), virtually any task involving thought can be viewed as problem solving. In the literature, this term refers to the achievement of a goal that is not readily available, within a set of constraints (Matlin, 1983; Haberlandt, 1997). Problem-solvers develop a representation of the problem and generate a solution path from the actual state to the desired state. Decision-making consists in choosing between the different courses of action available, that are uncertain, and enjoying or suffering the consequences of the chosen actions (Matlin, 1983).

2.2 Roots of CBR

According to Aamodt & Plaza (1994), part of the foundation for the CBR approach is its psychological plausibility. CBR is a collection of ideas for developing intelligent systems based on the fact that humans may rely on a memory of past cases to solve problems (McGovern, Samson & Wirth, 1994). The origins of CBR may be related to Shank's model of Dynamic Memory published in 1982. In his model, Shank considers that remembering, understanding, experiencing and learning cannot be separated from each otheer. Dynamic memory changes, as new events are experienced. The understanding of a new event is achieved by attempting to find the closest thing in memory resembling the new event, and then adapting the understanding of the memorized event (past event) to fit the new one. Consequently, in the course of understanding, old experiences are remembered, providing expectations that further drive the understanding process (Kolodner, 1993).

2.3 Logic under CBR

CBR is a problem-solving paradigm that resolves a new problem by recollecting a previous similar situation, and by reusing information and knowledge of that situation. CBR is an approach to incremental, sustained learning, since a new experience is retained each time a problem is solved, making it immediately available for future problems (Aamodt & Plaza, 1994).

To understand this approach, it is important to define the term "case". A case is a contextualized piece of knowledge representing an experience that teaches a lesson fundamental to achieving the goals of the reasoner (Kolodner & Leake, 1996). In its simplest

form, a case is a list of features that lead to a particular outcome. By contrast, in its most complex form, a case is a connected set of subcases that form the problem-solving task's structure (Barletta, 1991). Usually, the decision-maker possesses a lot of cases and he retrieves the appropriate ones to help him solve the problem. The similarities between the present problem and the retrieved cases will contribute to the solution of the present problem. A case-based reasoning system has three basic components, which are a) a library of historical cases, b) a need to use the key elements of the present problem to find and retrieve the similar cases from the case library and c) a means for making modifications to the proposed solution when the case on which the solution is based is not identical to the current problem. It is very important to properly construct and organize the library of cases, in order to allow for a better retrieving of cases. Inefficient searches in the case library due to its poor organisation can result in unacceptable performance.

2.4 The CBR Cycle

McGovern et al. (1994) and Aamodt & Plaza (1994) present two similar versions of the CBR cycle (see Figure 3). In this figure, grey boxes have been added to the original version of the cycle proposed by McGovern et al. (left) to illustrate the correspondences between the components of this cycle and the version presented by Aamodt & Plaza (right). Numbers in the right corners of these boxes indicate these correspondences.

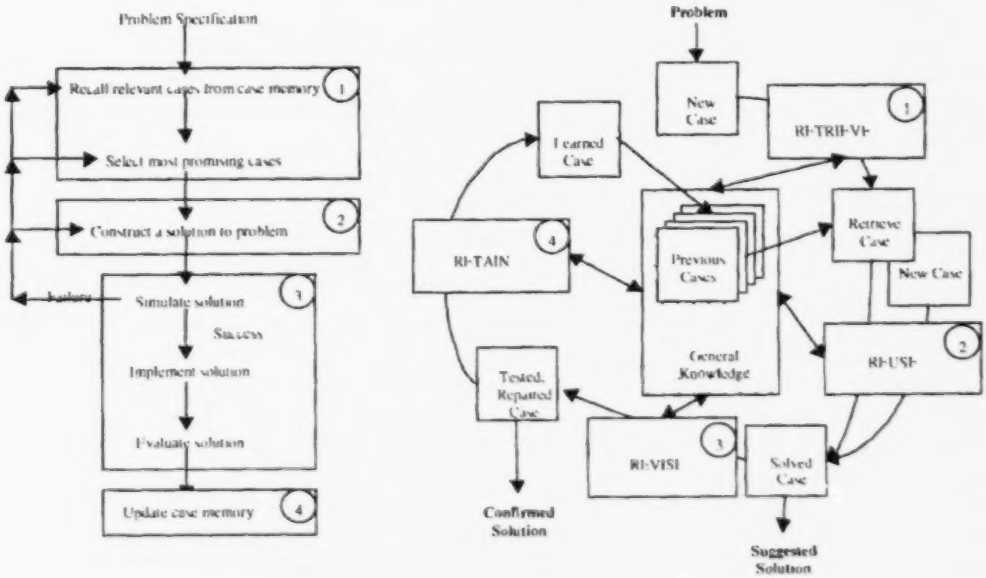

Figure 3. CBR Cycle proposed by (left) McGovern et al. (1994) and by (right) Aamodt & Plaza (1994)

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From these two cycles, four general components can be identified. First, after a problem has been identified, the information extracted from the environment initiates a search process in a case memory from which the most relevant and promising cases are retrieved. Second, a solution is built from the combination of the new case defining the problem and the retrieved cases. Third, the implementation of the solution proposed by the retrieved cases is simulated to determine if this solution can be adapted to the new case. If a failure is predicted from the result of the simulation process, other relevant cases are searched in the case memory. Otherwise, the solution is implemented. Finally, a learning process ensures the storage of the result of the implementation of the solution, which becomes a learned case that is added to the case memory.

2.5 Recall or Retrieval of Relevant Cases Process

The recall or retrieve task starts with a complete or partial problem description. The identification of the problem may be as simple as identifying the input descriptors of the problem or as complex as attempting to understand the problem within its context. The problem descriptors or features are used as indexes to retrieve a set of plausible candidates from the case memory. Cases that match all features are seen as good candidates. However, cases that only match a given fraction of the features may also be retrieved. The cases are eventually ranked according to some metric or ranking criteria.

The case representation (in terms of features), indexing, storage and retrieval are key concepts of the recall or retrieval process. According to Barletta (1991), determining the appropriate case features is the main knowledge-engineering task in CBR systems. The representation problem in CBR is primarily related to deciding what to store in a case, finding an appropriate structure for describing case contents, and deciding how the case memory should be organized and indexed for effective retrieval and reuse (Aamodt & Plaza, 1994).

The effectiveness of a CBR system is highly related to its capacity to retrieve relevant cases quickly and accurately from its memory. Kolodner & Leake (1996) consider that the indexes of a case act like indexes to books in a library. A case's indexes represent combinations of its important descriptors, the ones that distinguish it from other cases. Indexes must be abstract enough to retrieve a relevant case in a variety of future situations, as well as be concrete enough to be easily recognisable in future situations. The indexing process is crucial in the storage and the retrieval processes of a case. An appropriate label must be assigned to a case during the storage process. The appropriateness of the label will ensure that the case is retrieved at the proper moment. The organisation of the case memory is also important for the effectiveness of the CBR. Some memory structures are purely associative (features of a case are indexed independently) and others are purely hierarchical (features are highly organized into a general-to-specific concept structure). According to Barletta (1991), these two types of memory organization are related to the amount of knowledge available to perform indexing and the retrieval needs of the system. Flexibility will be favoured by an associative approach. However, a hierarchical approach will provide faster retrieval time.

2.6 Construction of a Solution or Reuse Process

To reuse the retrieved case solution in the context of the new case, the differences between the past and the current case and what part of the retrieved cases can be transferred to the new case must be considered. These considerations suggest that the adaptation process is a key concept for the construction of a solution. In adaptation, one takes a problem description and a solution that is not quite appropriate and manipulates the solution to make it fit the problem description in a more suitable manner (Kolodner & Leake, 1996). The adaptation process may be as simple as substituting one component of a solution, or as complex as modifying the whole structure of the solution. According to Aamodt & Plaza (1994), the adaptation process can be performed by reusing the past method that constructed the solution (derivational reuse). This approach considers how the problem was solved in the retrieved case that holds information about the method used for solving the retrieved problem, including a justification of the operators used, subgoals considered, alternatives generated, failed search paths, etc. Derivational reuse can be seen as a replay, in the new context, of the old plan that led to the retrieved solution.

The adaptation process is problem specific. The adaptation needs and approaches for one problem may be different from the adaptation needs for another (Barletta, 1991). For this reason, it is difficult to define a single generically applicable approach to perform case adaptation. Adaptation occurs when a problem is detected or anticipated with the application of a specific solution. The problem can be detected by the simulation of the application of the solution, or by the actual application of the solution in the real world. The anticipation of a problem may lead to the reformulation of a solution.

2.7 Simulate/Implement/Evaluate or Revise Process

Once the solution has been constructed, it is simulated through a simulation program. The result of this simulation is analyzed to detect possible errors, and to retrieve or generate explanations for them. The detection of errors may lead to a modification of the proposed solution. Once the simulation of the suggested solution provides an acceptable output, the solution is implemented in the real world. The implementation of the solution is evaluated and leads to the learning process.

2.8 Update Case Memory or Retain Process

According to Aamodt & Plaza (1994), the learning from success or failure of the proposed solution is triggered by the outcome of the evaluation and possible repairs. It involves selecting what information to retain from the case, the format to retain it, how to index the case for later retrieval from similar problems, and how to integrate the new case in the memory structure.

According to Kolodner & Leake (1996), a case-based reasoner becomes more efficient over time as a result of collecting more experiences and indexing them properly. The experiences must be analyzed in terms of what did work, what did not, and why. The learning process is determined by the accumulation of new cases and the assignment and unassignment of

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indexes. The performance of a case-based reasoner increases by remembering old solutions and adapting them, rather than having to derive answers from scratch each time. A case-based reasoner becomes more competent over time, deriving better answers than it could with less experience. With the increase of the number of cases in its memory, the case-based reasoner can anticipate mistakes, identify similarities between cases, and increase its familiar contexts for solving problems or evaluating solutions. Therefore, a case-based reasoner whose cases cover more of the domain will be a better reasoner than one whose cases cover less of the domain.

2.9 Advantages and Disadvantages

Case-based reasoning is patterned after human reasoning. According to Gonzalez & Dankel (1993), there are some advantages and some disadvantages in using it. Typically, the problems faced in the past will be compared to the current problem, and the solution of the previous problem that is the most similar to the current problem is then adopted. In some circumstances, the library of cases already exists and, consequently, the knowledge acquisition process is simplified. For instance, the base of experiences used can be that of an entire organization, and not that of a single person. The disadvantage associated with the case-based reasoning is essentially the computational cost of a solution. It can be quite expensive to perform a search in a large case library if this library is poorly indexed. The issues of proper indexing, library architecture, quality and number of the cases included in the library of cases are important factors in the development of a case-based system.

3. Recognition-Primed Decision Model

Elaborated by Klein (1988, see also Klein, Calderwood, & MacGregor, 1989), the RPD model stipulates that rather than weighting advantages and disadvantages of several alternatives, experienced decision makers use their experience to evaluate a situation and directly determine a solution or a possible course of action from the first attempt.

According to this model, decision-making starts with a recognition process of the current situation that is based on the degree of familiarity of this situation in comparison to one's mental index and experience. If the situation appears unfamiliar, the decision-maker will seek further information. On the opposite, if the situation is classified as familiar, a process that consists in understanding the situation in the light of expectations and recalling relevant prototypic actions from prior experience is initiated. Each action is then evaluated independently; i.e., not in comparison with other alternatives as it was proposed by traditional models of decision-making. Afterwards, through mental simulation, there is an evaluation of the potential and plausible consequences of each considered course of action. Thus, the decision-maker will mentally visualize how the situation could potentially evolve if a particular action was to be implemented (Beach, 1997).

Based on the RPD model, naturalistic decision-making can be achieved at three different levels: Simple Match, Diagnosis of the situation, and Evaluation of the Course of Action. The result of the decision-making process for each of these levels is the implementation of the action, but each level includes various steps allowing for adaptation in regard to the complexity and familiarity of the situation. The first level, the Simple Match, is activated when the current situation is simple and straightforward; i.e., the crucial elements of the situation, the objectives, and the typical course of action to implement are easily recognized and identified (Klein, 1996; 1997).

The second level, Diagnosis, is activated by the presence of uncertainty concerning the situation. At this level, there is an attempt to establish a relationship between an event and causal factors. Therefore, Diagnosis allows the decision-maker to define the situation and to find an explanation for it. Because of the fact that the action chosen depends on the evaluation of the situation, diagnosis appears to be particularly important in situations stamped with uncertainty, like C^2 settings (Plous, 1993; Klein, 1997). Diagnosis is an integrated part of the decision-making process.

The third level, the Evaluate Course of Action, is required with more complex situations. It implies the mental simulation of the foreseen course of action to evaluate potential difficulties, possible solutions and, consequently, to determine if this action must be implemented or if further evaluation is required to identify a new course of action (Klein, 1997). The evaluation process can also lead to the modification of the course of action.

According to Klein (1996), decision-makers use different strategies in relation to the level involved in the decision-making process (levels 2 or 3). For the diagnosis level, strategies are grouped around a principal objective; i.e., the size up of the situation and the identification of singularities. The most frequently used strategy at that level is feature matching that consists

of a comparison between the characteristics of the current situation and different hypotheses resulting from the identification process that could explain the nature of the situation. Results from a study conducted by Kaempf, Klein, Thordsen & Wolf (1996), based on naval incidents, have shown that 87% of the decisions concerning the nature of the situation were based on feature matching. This study also demonstrated that a second strategy, story building, is used in 12% of the decisions. This strategy consists of the elaboration of a story from both one's previous experience and the elements present in the situation. Thus, a decision-maker not only tries to compare determining characteristics as in feature matching, but he or she will also attempt to link all available information together to establish causal relations (Klein, 1996). Strategies that are related to the third level of the RPD model, i.e., those involved in the selection of a course of action, require a deeper elaboration from the decision-maker, because of the complexity of the situation. These strategies of the Evaluate Course of Action level are based on the mental simulation of the envisaged course of action to first determine how it will be implemented and executed, and then to identify potential difficulties and possible solutions.

According to Klein (1995), experienced decision makers can directly identify a reasonable good option as the first one they consider, rather than treating option generation as a semi-random process, requiring the decision maker to generate many options. Instead of trying to find the optimal solution, the RPD model relies on the most satisfying one. Following the identification of a satisfying option, experienced decision makers evaluate that option by conducting mental simulations of a course of action to see if it will work, rather than having to contrast strengths and weaknesses of different options. Finally, by way of a recognitional strategy, actions can be undertaken before the end of the analysis process if the decision-maker finds the option adequate. Formal strategies in which all options must be evaluated before the initiation of any actions are more frequently used by decision-makers with less experience.

4. Parallels Between the RPD and the CBR approach

4.1 Pattern Recognition

RPD and CBR models are both initiated by a pattern recognition process. This feature matching process consists in identifying features from the environment that are meaningful for the decision-makers. These features are used as indexes for the retrieval of relevant information stored in the memory case (CBR) or the long-term memory (RPD). The quality of these indexes is a critical factor in both models. In CBR, good indexes lead to the recovery of an appropriate case, which in turn leads to the implementation of an appropriate course of action. In RPD, the ability to recognize patterns can be seen as a major difference between experts and novices. Experts are trained to recognize relevant features (relevant indexes) that lead to the selection of the appropriate course of action. Therefore, for both models, the pattern recognition process seems conceptually similar.

4.2 Construction of the Solution

In both the CBR and the RPD models, once a specific pattern of features has been recognized, a solution is proposed. The selection of this solution is based on the number of features shared by the situation and the proposed solution. CBR systems recall the most promising cases from which the best option is selected. According to the RPD model, decision-makers use their expertise to immediately identify the most appropriate option. This option is tested mentally and the results of this mental simulation determine if another option is required. In both of these models, once an option has been selected, it is tested independently of other possible options. For both models, the proposed solution can be modified if the evaluation process reveals possible problems. Additionally, in RPD, the detection of problems may also lead to a search process for new information in the environment.

4.3 Simulation Process

The CBR and RPD models both propose a simulation process. In CBR, the solution resulting from the adaptation or the modification of past cases is tested. The result of the simulation indicates the need for further modifications, or the implementation of the solution in the real world. This simulation process shares some similarities with the one included in the RPD model. In the latter, the mental simulation is performed to verify the presence of possible problems and difficulties. However, there is a slight difference between the simulation processes included in the CBR and the RPD models. In RPD, the action can be implemented without being tested by the mental simulation process. This situation happens either when there is a perfect match between features of the situation and features stored in the long-term memory, or when the action is immediately required by the situation (time pressure). In CBR, the solution must be simulated before its implementation.

4.4 Development of the Expertise

In a CBR system, the performance of the system is improved by the addition of new cases. A learning process allows the storage of the result of the implementation of the action, and of the conditions of this implementation. In RPD, the development of the expertise must be associated with the role of mental models. Although this mental model construct is not an integral part of the RPD model, Lipshitz & Ben Shaul (1997) suggest that it is implicitly included. In order to evaluate the familiarity of a situation, this situation must be compared with a mental model that is constructed by experiencing various situations. A novice becomes expert by constructing these mental models, and by storing the appropriate ones.

Conceptually, there is a similarity between the description of a case and the description of the mental model. A case is a contextualized piece of knowledge representing an experience that teaches a lesson fundamental for achieving the goals of the reasoner (Kolodner & Leake, 1996). Mental models can be seen as a mental representation of specific situations (Serfaty & MacMillian, Entin, & Entin, 1997). Table 1 presents a summary of the similarities between the RPD and CBR approaches issued from different perspectives (human factor versus technological).

Table 1: Similarities between the RPD and the CBR Models

The CBR Model	The RPD Model
Pattern Recognition and Feature Matching Identification of features in the environment (indexes) that initiates a search process in the memory case.	**Pattern Recognition and Feature Matching** Evaluation of the degree of familiarity between the features of a situation and past experiences stored in the long-term memory.
Construction of the solution The solution is chosen from a set of the most promising options. This set is selected from the feature matching process.	**Construction of the solution** With their expertise, the decision-makers generate the most promising option. This option is chosen from the feature matching process.
Simulator Program According to the results of the simulation process, the new case can be replaced or modified.	**Mental Simulation** With a conscious evaluation through mental simulation, the chosen course of action can be replaced by a new one or modified.
Expertise development A learning process ensures the storage of the result of the implementation of the solution, which becomes a learned case that it added to the memory case. The CBR system becomes more efficient over time as a result of this learning process.	**Expertise development** Within the RPD Model, expertise is a key component. Although it is not properly part of the RPD Model, experienced decision-makers rely on mental models to rapidly size up a situation and generate options.

5. Conclusion

As mentioned in introduction, C^2 activities take place in a very complex environment in which unpredictable events may challenge the fulfilment of the mission. Accordingly, computer system and human strengths are required to cope with the complexity and uncertainty of the C^2 environment. The challenge facing the design team of a decision-support system is to create a system that supports the human in his/her limitations, without constraining him/her in his/her strengths. In addition, the processes supported by the DSS must be familiar to the decision-maker and be appropriate to the situation at hand (Smith & Marshall, 1997). To address these issues, system designers and human factor specialists must share a compatible representation of the task to be performed, as well as understand the constraints and possibilities inherent to the task. In others words, the solutions proposed from both perspectives must be conceptually compatible. This document presented conceptual similarities between the Case-Based Reasoning approach, issued from a technological perspective, and the Recognition-Primed Decision Model, issued from a human factor perspective.

Because of these conceptual similarities, designing a DSS from the CBR approach is attractive. CBR systems have great capacities for pattern recognition and case retrieval. Since the human being has limited perceptual and memory resources, CBR capacities directly support humans in their limitations. In the context of the OODA loop (Observe-Orient-Decide-Act), the pattern recognition capacities of CBR may be useful in the Observe phase. Furthermore, the simulation program may be very useful in the Orient and Decide phases of the OODA loop. This program typically has the capacity to simultaneously consider more features than a human can consider in a mental simulation activity. Therefore, the simulation program can be useful to provide an organization of all these features, and the choice of an appropriate course of action.

However, there exist some constraints associated with the CBR application in the Naturalistic Decision-Making context. First, an extensive amount of work is required for the construction of the memory case and the storage of specific cases that make the recognition process possible. Second, the introduction of the information (features) by the user in the CBR system may expand rather than reduce the human workload. Furthermore, with the development of human expertise, when patterns can be directly recognized by the user, the augmented evaluation process provided by the CBR may become useless. Finally, the use of a CBR system may not be appropriate in situations characterized by time pressure. In these situations, even when a pattern seems unfamiliar, there is no time for the introduction of the features into the CBR system, and the delays associated with the evaluation processes of the system may become an important issue. Therefore, the application of the CBR system in NDM may be seen as inappropriate in situations for which there is time pressure, and useless in situations involving familiar patterns. However, the conceptual similarity between the CBR and the RPD models, makes the CBR approach appropriate to support every phase of the human decision-making process involved in a NDM environment.

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Evidences have been brought concerning the utility of the Naturalistic Decision-Making (NDM) model in military Command and Control (C2) NDM may be seen as a good representation of the environment in which C2 activities take place NDM represents situations marked by uncertainty, time pressure, high stakes, ill-structured problems, competing or conflicting goals, etc Developed from a Human Factor perspective, the Recognition-Primed Decision model (RPD) represents how the humans are making decisions in the NDM context. According to the RPD model, the pattern recognition and mental simulation phases seem determinant for the human performance. Therefore, from a technological perspective, Decision Support Systems (DSS) must support these phases to efficiently support the human decision-making processes in the NDM context. In business management and manufacturing contexts, the Case-Based Reasoning (CBR) approach has been successfully used to support decisional processes These systems, in which pattern recognition and simulation are key components, concentrate on knowledge acquisition, and the cognitive areas of learning. The contexts of CBR applications may be different than the one defined by the NDM. However, there are some very interesting similarities between the CBR and the RPD architectures. This paper presents these similarities and discusses the possible application of CBR concepts to the decision-making processes involved in the NDM context.

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